Mutual Interference: Probability of Antenna Boresighting

P_1 = Probability antenna #1 looking at antenna #2

P_2 = Probability antenna #2 looking at antenna #1

P_{DIR} = Probability both antennas moving same direction (CW or CCW) = 0.5

$$P_{ANT} = P_1 \cdot P_2 \cdot P_{DIR}$$

For our system, $P_1 = P_2 = 0.1$ for straight road, adjacent opposing lanes (worst case)

$$P_{ANT} = (0.1)(0.1)(0.5) = .005$$

Mutual Interference: False Alarm Rate

- For an automobile equipped with the GMHE radar, P_{FA} is the probability that a similar system will cause it to generate a false alarm
- Suppose one encounters n such (similar) systems every second
- P_{FAPH}: The probability that at least one false alarm is generated over a period of one hour is

$$P_{FAPH} = 1 - \left(1 - P_{FA}\right)^{3600N}$$

- For small P_{FAPH}, the false alarm rate (FAR), i.e., one false alarm per FAR hours:

$$FAR = \frac{1}{P_{FAPH}}$$

Mutual Interference: False Alarm Rate Estimate

- Assume n=1 encounter per second
- Nominal system parameters:
  IFBW = 100 KHz
  Slope = 50 MHz/ms
  T = 4 ms
- Bandwidth (W) = 800 MHz:
  $P_{SYN} = 0.001$ $P_{OVLP} = 0.00025$ $P_{ANT} = .005$
  $P_{FA} = 1.25E-9$
  $P_{FAPH} = 4.3E-6$
  FAR = 1 in 231,000 hours

Mutual Interference: Calculated FAR Estimates Are Very Conservative

- Assumes antennas of interfering radars are looking directly at each other and this occurs once per second
  - Should not happen on divided highways
  - Could happen on roads with adjacent opposing lanes and no barrier
- "Target Selection" algorithm will eliminate alarms for targets not in path of radar car
- Assumes FM slopes are identical for every unit; not true due to manufacturing tolerances; differences in actual slopes significantly reduce probability of frequency overlap

B

Appendix B:

Initial Analysis of a Sharing Criteria at 76 GHz

The *NPRM* proposes that 76 GHz vehicular radars share their band with amateur, amateur satellite, Government space research, and Government radars. This raises the need for a sharing criteria that allow these other services to operate without interfering with the important public service provided by vehicular radars. In the absence of specific proposed services, there are obvious limitations to how complete an analysis can be undertaken, but some preliminary analysis is possible and has been done by HEM and Hughes engineers for the proposed HEM vehicular radar system.

The goal was to calculate a level of CW signal that clearly would not interfere with the performance of the vehicular radar.[1] The starting point is to recognize that the only interfering signals that are relevant are the signals that would enter the receiver of a vehicular radar that is placed on the front center of a vehicle about 2 feet above the highway surface. Thus, the relevant signal to consider is the field strength placed two feet above the center of a lane on a public highway. Subsequent discussion will show that substantial relaxation of the criteria is possible on public highways where vehicle speeds are below roughly 45 mph.

The limiting interference phenomena to analyze for a CW signal is that the interfering signal adds to the noise floor of the vehicle radar ("radar") and causes a valid target to become obscured. The basic method of analysis is as follows. First the relevant target signal is calculated. From this, a maximum allowed received interfering signal is calculated. This permits the calculation of the allowed interfering power density 2 feet above the surface of public highways as a function of the angle of arrival.

The desired received signal is calculated from the standard radar equation:

$$TARGET = \frac{P_{FLR} G_{FLR}^2 \lambda^2 \sigma}{(4\Pi)^3 R_{TGT}^4 L_{Beam(FLR \to TGT)}^2}$$

The following values were used to calculate received power from the Target:

P_{FLR} = 10 mW	G_{FLR} = 35 dBi	$\lambda = 3.92 \times 10^{-3}$ m
$\sigma = 1\ m^2$	R_{TGT} = 120 m	$L_{Beam(FLR \to TGT)}$ = 3 dB

The radar cross section (σ) and range to target (R_{TGT}) are conservative (worse case) assumptions about actual conditions. The other values represent typical values for the HEM type radar under development. This results in a target signal of:

TARGET = 933×10^{-15} W

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1 While the formal analysis was limited to a CW signal, these results should be generally applicable to a wide variety of signals whose energy is within the bandwidth of the HEM type of system.

Previous analysis has shown that with a CW signal, target detection is degraded with the HEM type radar when the interfering signal is 31 dB above the target signal. Thus, the allowable received interference signal (INT) is:

$$INT = 1.2 \times 10^{-9} W$$

Based on the relationship between power density (S) and received signal strength, the allowable power density of the CW interferor signal can be calculated:

$$S = \frac{INT \bullet 4\Pi}{\lambda^2 \bullet G_{FLR}} = \qquad 306 \times 10^{-9} W/m^2$$

Power densities created by a CW interferer below this threshold value will not significantly degrade performance of the HEM type radar. However, in most cases power densities arriving 2 feet above the center of a public road can be higher than the value given above. This is because the 306 nanowatts was calculated using the maximum gain of the receive antenna ("boresight"). The radar actually uses a highly directional receive antenna so that any arriving interfering signal that is not perfectly aligned with the receive antenna will be attenuated by the antenna pattern.[2]

While both vertical and horizontal angle of arrival are important, for purposes of this analysis we have assumed that the vertical angle of arrival is zero (a highly conservative assumption) and have only computed allowable power density as a function of horizontal arrival angle (θ) defined in Figure 1. Based on the antenna pattern of the HEM type radar, we can then define the allowable power density as a function of the horizontal arrival angle. The results of these calculations are shown in Figure 2. Points to the lower right of the curve (i.e. combinations of power density magnitude and horizontal arrival angle) represent situations that can clearly be coordinated. Points on the upper left of the curve will need to be examined on a case-by-case basis.

The curve in Figure 2 is flat for the first 8° on either side of the center line because of the possibility that the road ahead may curve right or left immediately in front of the car. Thus, if the road ahead curves to the right, the receive antenna will be boresighted on potential targets down the road when the antenna is turned to the right of the vehicle's current centerline. Valid targets will not be beyond 8° to either side of the centerline.[3] Beyond this, the angular discrimination of the receive antenna allows higher interfering power densities as shown in Figure 2.

Obviously, a given power density impinging on (or to be more precise, two feet above the center of a lane on) a public road can be created by an almost infinite combination of transmitted EIRP and distance from the public highway. To give some sense of the powers allowed by Figure 2, we have computed, using the free space relationship, combinations of transmitter EIRP and horizontal angle of arrival as follows:

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2 Recall that any far field power density is actually a vector of both quantity and direction.

3 This is based on the fact that under applicable Federal Highway Administration guidelines, higher speed highways will have a minimum radius of curvature of approximately 400 meters.

ALLOWED EIRP
(Free Space Propagation)

Distance	Horizontal Angle of Arrival (θ)		
	Boresight	20°	60°
500 m	1 W	100 W	10 kW
10 km	383 W	38 kW	3.8 MW

The actual allowed power (EIRP) is likely to be substantially higher, especially at longer distances, since atmospheric attenuation and path obstruction (particularly with the assumption of no vertical antenna pattern attenuation) will increase attenuation substantially above the free space values used in this table.

The other key factor that needs to be considered is highway speed. A crucial assumption in the calculation of Figure 2 is the range (R_{TGT}) at which a target needs to be unobstructed by the interfering signal. The value used in this analysis, 120 meters, was chosen to provide adequate margin at speeds allowed on limited access highways. In cases, where actual vehicle speeds are substantially below this (say below 45 mph), then the distance to the target can be decreased substantially. Since the received target signal strength varies with R^{-4} even small reductions in the range can have a significant impact on received signal strength.

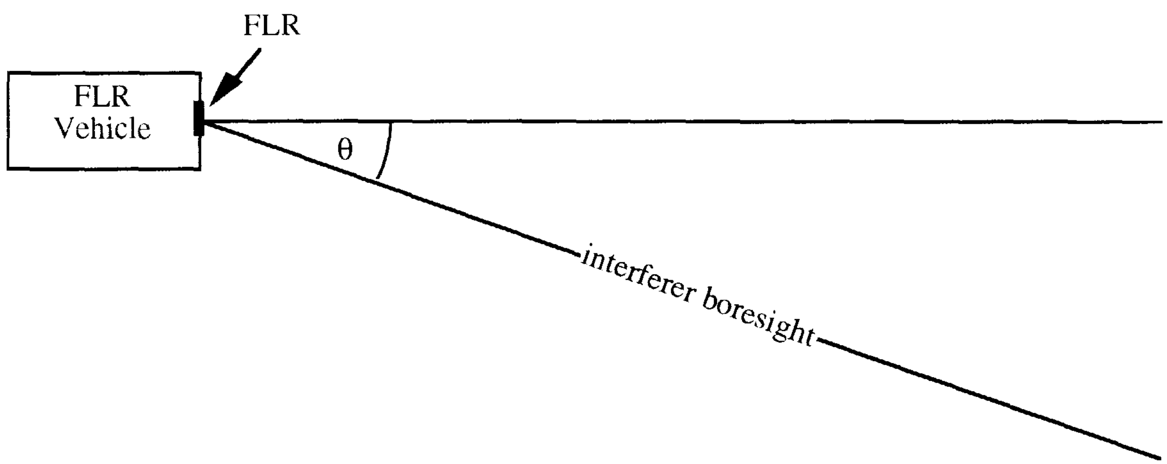

Figure 1 - Angle of Arrival

Figure 2 - Power Density Limits as a Function of Angle of Arrival